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VOLUME 1 — FINAL REPORT

for Period February 26, 1962 to February 25, 1963

STUDY OF DYNAMIC AND STATIC SEALS
FOR LIQUID ROCKET ENGINES

NASA Contract No. NAS 7-102

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DESCRIPTION OF PROGRAM
AND
RESULTS OF EVALUATION OF CURRENTLY
AVAILABLE SEALING METHODS

R. C. Elwell
A. J. Bialous

Volume 1 - Final Report

March 29, 1963

Study of Dynamic and Static Seals
for Liquid Rocket Engines

Contract Period - February 26, 1962 to February 25, 1963

TO: Chief, Liquid Propulsion Systems, RPL
National Aeronautics and Space Administration
400 Maryland Avenue, S.W.
Washington 25, D.C.

PREPARED BY: Advanced Technology Laboratories
General Electric Company
Schenectady, New York

CONTRACT NO: NAS 7-102

CONTRACTING DEPARTMENT: Missile and Space Division
Philadelphia, Pennsylvania

CR-50,663

I. SUMMARY

195-95

This is the first volume of a report which describes the technical efforts applied in the performance of Contract NAS 7-102, between the National Aeronautics and Space Administration and the General Electric Company (Missile and Space Division). The technical work was accomplished by personnel of the Advanced Technology Laboratories, (formerly the General Engineering Laboratory), of the General Electric Company.

The title of this program is "Study of Dynamic and Static Seals for Liquid Rocket Engines." The objective of the program is to advance the technology of dynamic and static seals for liquid rocket engines of all types.

In the period being reported on here, the main elements of the technology of sealing have been defined, and the present state of knowledge in most of these areas established.

Studies have been conducted in several of these areas, as described below. In addition, extensive surveys have been conducted of two main bodies of technical literature--U.S. Government reports and open literature. The data derived from this task is being analyzed to establish the detailed capabilities of existing sealing methods. It has been found necessary to perform these two efforts because of the disorganized state of the literature in this technology.

The results of these various studies are presented in this report, which consists of four separate documents, summaries of which follow.

Volume 1 (This document) - Description of Program and Evaluation of Currently Available Sealing Methods

The first part of this publication gives an overall description of the study, including its objective, scope, strategy and tactics. An analysis of the results of the study in overall terms is also included.

An appendix contains tables of data thus far reduced from published information. These tables are intended to furnish a quick guide to the capabilities of any particular sealing device.

Volume 2 - Studies on Special Topics in Sealing

Detailed reports are presented here on the specific individual studies carried out on the following subjects:

- A. Gas Permeation Through Solids
- B. General Seal Analysis
- C. The Labyrinth Seal
- D. Leak Detection and Measurement
- E. Cryogenic Sealing
- F. Two Phase Phenomena in Dynamic Face Seals
- G. Seal Materials

Volume 3A - Bibliography of ASTIA Literature on Seals

This publication contains 682 abstracts of government reports available from the Armed Services Technical Information Agency (ASTIA). A complete Subject Index in the back allows rapid searching for references on particular topics. Definitions are included.

Volume 3B - Bibliography of Open Literature on Seals

This publication contains 1482 abstracts of references available to the general public on the subject of sealing. As in the case of the ASTIA bibliography in Volume 3A, a complete subject index with definitions is included. With Volume 3A, this constitutes the most extensive bibliography on this subject known to exist, and is the final document in this report.

Project Engineer is R. C. Elwell. Project Manager is G. R. Fox. This study is being conducted within the Mechanical Engineering Laboratory, which is one of the Advanced Technology Laboratories.

NASA Technical Manager is R. S. Weiner, Liquid Propulsion Section, Jet Propulsion Laboratory. NASA Project Manager is F. E. Compitello, Code RPL, Office of Liquid Rockets.

II. DESCRIPTION OF PROGRAM


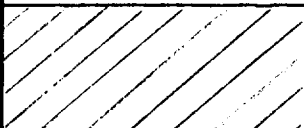


A. Objective

The objective of this program is to advance the technology of dynamic and static seals for liquid rocket engines. A study of the fundamentals of sealing processes is to be carried out, in order to provide the understanding necessary to formulate design criteria for seals in future liquid rocket engines.

B. Scope

The scope of this program may be represented diagrammatically as follows, with the shaded areas representing the areas of interest in this study:

Scope of Study of Dynamic and
Static Seals for Liquid Rocket Engines

	STATIC SEALS	DYNAMIC SEALS
Launch Vehicles		
	Connectors	
Space Vehicles		

The study of "zero leakage" connectors for launch vehicle engines is the subject of a separate NASA study at ATL.

C. Strategy

Our basic strategy in attaining the above objective may be described in simplified fashion as follows:

1. Reduce the sealing technology to its main technical areas, for further detailed study in each area. This essentially established the "road map" of the project. The reduction we are using for working purposes appears in Figure II-1 of this Section.

2. Acquire all information possible on static and dynamic sealing technology, and organize this so that the present state of the art may be apparent in all these areas. This required a comprehensive literature search, since this had never been done, and the results of prior work in this field were scattered in many places.
3. Appraise the state of existing knowledge and experience in each area, on the basis of the information acquired in the previous step. This may be represented pictorially as in Figure II-1, which presents our present estimates of the state of each area.

The following working definitions are being employed as standards in the study:

- a. Poor: Basic principle unknown. Empirical data serves as basis for design and use.
 - b. Fair: Basic principle known. Analytical techniques for performance prediction not available.
 - c. Good: Analytical prediction of performance possible with rough (say $\pm 25\%$) accuracy.
 - d. Excellent: Performance analytically predictable with high accuracy (say $\pm 5\%$).
4. Simultaneously with the previous step, establish how much knowledge will be needed in each area for the design of future liquid rocket engines. The overall length of the bars shown in Figure II-1 represent

our current opinions.

5. Furnish the knowledge necessary to advance the technology in the areas where this has been determined to be necessary in the previous steps. Whereas the previous tasks may be regarded as defining the present position of the technology, they cannot advance it by themselves. Therefore, this final step is required in the overall strategy in order to attain the objective.

D. Tactics

In general, our program tactics may be described as carrying out a broad advance across the field illustrated in Figure II-1, and at the same time advancing the technology in specific areas where we know definitely that an advance is necessary and feasible to attain. Volume 2 presents the results of most of these studies. The Appendix of this volume contains the results of the evaluation of present sealing techniques as it now stands.. Volume 3 presents the results of our study of the literature.

Figure II-1

MATRIX OF STUDY OF
DYNAMIC AND STATIC SEALS
FOR LIQUID ROCKET ENGINES

		POOR	FAIR	GOOD	EXC.
FLUID SEALING TECHNOLOGY	STATIC SEALING	A. Selection and Control of Geom.			
		1. Positive Contact			
		2. Controlled Clearance			
		B. Control of Fluid Properties			
		1. Freeze			
		2. Magnetic			
		3. Other Types			
		C. Control of Fluid Forces			
	DYNAMIC SEALING	A. Rotary Motion			
		1. Selec. and Cont. Geom.			
		2. Control Fluid Properties			
		3. Control Fluid Forces			
		B. Oscillatory Motion			
		1. Selec. and Cont. Geom.			
		2. Control Fluid Properties			
		3. Control Fluid Forces			
		C. Reciprocating Motion			
		1. Selec. and Cont. Geom.			
		2. Control Fluid Properties			
		3. Control Fluid Forces			
GENERAL AREAS	A. Leak Detection and Meas.				
	B. Materials Problems				
	C. Cryogenic Fluids Sealing				
	D. Permeation Flow Phenomena				
	E. Fundamental Analytical Work				
	F. Literature				
	G. Other				



Estimate of Present State



Estimate of Advance Required for Future Liquid Rocket Engines

III. ANALYSIS OF RESULTS OF PROGRAM

A. General

In our discussions with technical personnel in various aerospace industry and government establishments, propellant leakage was consistently described as a major problem. Also, our efforts to effect an improvement in fundamental knowledge of sealing were generally encouraged, because of the difficulty experienced in solving problems without it. It appears that the condition of the technology as we found it was largely due to a history of one-shot problem solving programs which contributed little knowledge to the field.

Our impression is that the problem of generating this fundamental knowledge has been too big to be accomplished in the small scale efforts usually applied to seal problems. Unless this situation is corrected, particularly in regard to analytical ability, the empirical solve-one-problem-at-a-time approach is going to be extremely costly in time and money in the future, when propulsion systems get larger and more complex.

Overall, we have found the technology of fluid sealing to be in a rather disorganized state and not as technically mature as many others such as heat transfer or lubrication, to cite familiar examples. There are no books, for example, except for two small volumes in German, and until the inception of this study, there was not even a bibliography on the subject.

One of the major results of this program, prosaic though it may sound, was the establishment of the main elements of the technology (See Fig. II-1), previous page) in an orderly structure. We do not claim that this outline is final or perhaps even the best organization, but it will at least serve the purpose of presenting a "target," or example, for future improvement, and serve as a framework for discussion.

D. Gas Permeation Through Solids (See Vol. 2)

In storing gases for long periods of time, such as in some projected spacecraft, losses due to this process could be significant. Our study of the state of the art is presented in Volume 2. It is concluded that more experimental data is required in order to adequately predict long time flow losses because of this.

E. General Seal Analysis (See Vol. 2)

It has been necessary to start on a very fundamental level in this area, because the sealing technology suffers from a particular weakness in analytical techniques. Derivation of the basic equations for analysis of flow between concentric vertical cylinders and parallel plates is presented, using tensor notation.

It is hoped that these basic derivations will serve as a foundation for future specialized analyses of many types of sealing devices, in a fashion analogous to the Navier-Stokes equations in fluid mechanics.

F. The Labyrinth Seal (see Vol. 2)

A survey was conducted of present knowledge and design ability on this device, which is particularly important because of its wide use in liquid rocket engine turbomachinery. It is found that design information on this type of seal is in a much better state than most other dynamic sealing devices.

G. Leak Detection and Leakage Measurement (See Vol. 2)

A rather extensive report was prepared on the state of the art in this area, which is directly related to sealing in that evaluation of seal effectiveness is just as important as design ability. Topics covered include types of leakage flows, conversion of flow rates to standard conditions, and leakage

A further accomplishment along these organizational lines was the preparation of an extensive group of definitions. These are placed for convenience in the Subject Indexes of Volumes 3A (pp. 187-208) and 3B (pp. 147-161). By incorporation of the subsequent suggestions and criticism expected after issuance of this report, this list should serve a valuable function in the potential establishment of standard terms.

B. Literature on Seals and Sealing (See Vol. 3)

For a technology which has been of such wide interest over the years, the state of its literature as we found it was a source of amazement. By coincidence, two excellent bibliographies of limited scope appeared shortly after we initiated an exhaustive survey (See Vol. 3B, pp. iii). These have been incorporated in Volume 3B, which goes back to the original publication of 23 major sources in the English language.

This effort alone will save countless man-hours of random literature searching in the future, not only by designers of liquid rocket engines, but by other industry and government personnel as well.

C. Evaluation of Currently Available Sealing Methods (See Vol. 1)

There is no book on this subject except as noted above, and one of those is 20 years old. A person setting out to design a seal or establish operating capabilities of a particular device, therefore, has no reliable place to look for what is available and what has been accomplished to date.

The Appendix of this volume is an interim report on the data we have been able to evaluate thus far in an attempt to produce a quick design reference. This effort could not be completed within this period because of the condition of the literature as discussed above. In this task, certain general references have been found useful and these are pointed out in this appendix.

testing methods. A considerable amount of work remains to be done on this topic, especially if sealing capabilities improve, which will require better standards and techniques.

H. Cryogenic Sealing (See Vol. 2)

This topic was singled out for a special state of the art evaluation due to the wide use of cryogenic propellants in both present and future engines. It was concluded that uniqueness of sealing problems in this area is mainly due to friction and wear of dynamic seals in atmospheres of propellant gases. A description of major current activities in this field is included.

I. Two Phase Phenomena in Dynamic Face Seals (See Vol. 2)

These devices are even more widely used than labyrinth seals (Appendix C) in rocket engines and are not understood to any significant extent. Most theoretical work has been concerned with the problem of fluid film load capacity in the device, to the apparent detriment of theories on the subject of the mechanism by which it seals. In this section a new theory of its function is presented, based on two phase fluid phenomena.

It is hoped that this will generate new ideas on this device, which frequently causes operational problems in dynamic sealing.

J. Seal Materials (See Vol. 2)

A limited effort was carried out in this area, and the results are documented in Appendix G of Volume 2. A limited number of materials have been used in most sealing devices, so that among the large number of other available materials there may be potentially superior ones untried thus far. A more extensive study is required in this area. A continuation of the evaluation of existing sealing techniques (see Appendix, this volume) is expected to document the most successful seal materials in more detail, and assist in this task.

There is of course considerable interrelation between several of the above studies. For instance, materials considerations are important to the studies on gas permeation, the labyrinth seal, cryogenic sealing, and the occurrence of the two phase phenomena in face seals. For another example, the occurrence of the two phase phenomena will ultimately be predictable through the results of the general analysis. Leakage measurement, of course, applies to all sealing applications.

APPENDIX

EVALUATION OF CURRENTLY AVAILABLE SEALING METHODS - A. J. BIALOUS

This is an interim report of an analysis and evaluation of published data on all types of sealing devices. The analysis has been conducted and the report prepared by the Advanced Technology Laboratories of the General Electric Company under NASA contract number NAS-7-102. The objective of this analysis is to establish the state of present knowledge of various sealing devices and to present this information in a clear, concise and convenient manner.

The primary source of information for this analysis has been the published results obtained in testing programs conducted on sealing devices. A few selected recommendations made by persons and organizations considered to be eminent in this field or in related subjects, have also been included. Data presented is limited to that obtained during tests in which the seal has been considered to perform in a satisfactory manner under stated application and environmental conditions.

The published information initially reviewed was in abstract form and is in general, limited to the abstracts listed in Volume 3A of this Final Report. These are unclassified abstracts which have been supplied by ASTIA (Armed Services Technical Information Agency) on the subject of static and dynamic seals. A few of the open-literature abstracts in Volume 3B of this Final Report have also been reviewed. In this latter area, considerable emphasis has been given to general seal references.

Each of the approximately 700 listed ASTIA abstracts was reviewed and analyzed for applicability. It had been estimated that about half of the

necessary data would be obtained from these abstracts, but the dearth of information given in a substantial number of them requires that the complete reference be read so that information of sufficient depth can be obtained. Most of the ASTIA reports which have been selected for reading have been accumulated. Experience, based primarily on the review of ASTIA abstracts indicates the following findings as oriented to this program:

1. Abstracts which contain useful information----- 5%
2. Promising references to be read-----17%
3. Abstracts containing no significant information-----78%

A review of the data documented to date shows that 50% of the entries were made directly from abstracts and that in the remaining 50% of the cases, the original references were studied. A disciplined effort has been made to present only the facts given in the literature and not to make any interpretations, extensions or generalizations of these facts.

The documented data is presented in a handbook type of format (Tables 1-21) which permits rapid performance data evaluation. Information obtained from ASTIA reports can be identified in the tables by the ASTIA number which is usually preceded by the letters AD. Open literature sources are identified by the serial numbers assigned to them in Volume 3B. These numbers are preceded by the first letter of the author's last name.

Seal types listed, and definitions used, conform with those given on pp. 147 to 156 of Volume 3B of this Final Report. Information concerning the applicability of a particular type of sealing device for a specific system application, can be found in the tables under the heading of the sealing device for either static or dynamic application. (See List of Tables preceding Table 1). For example, performance data for O-Ring sealing methods used on rotating shafts are listed under O-Ring, Dynamic Seals in Tables 14

to 16.

Plans have been made to continue this analysis in greater depth. Included in these plans is the review of the approximately 75 selected ASTIA papers and the examination of the 1500 open-literature abstracts listed in Volume 3B of this Final Report.

Whereas the information presented in Tables 1-21 is organized on a seal-oriented basis for working convenience, ultimately it will be organized on a user-oriented basis. This user-oriented approach will permit a search to be concentrated on the sealing category of interest and will ignore other capabilities of a particular sealing device.

SEAL CATEGORIZATION SYSTEM

I. DYNAMIC SEALS

- | | | |
|---|--|--|
| <p>A. <u>Rotary Motion</u></p> <p>1. <u>Selection and Control of Geometry</u></p> <p>a. Positive Contact</p> <p>i. Face</p> <p>ii. Packings</p> <p>iii. Lip</p> <p>iv. Rings</p> <p>b. Controlled Clearance</p> <p>i. Labyrinth</p> <p>ii. Bushing</p> <p>2. Control of Fluid Properties</p> <p>a. Freeze</p> <p>b. Magnetic</p> <p>3. Control of Forces</p> <p>a. Centrifugal</p> <p>b. Screw</p> <p>c. Magnetic</p> | <p>B. <u>Oscillatory Motion</u></p> <p>1. <u>Selection and Control of Geometry</u></p> <p>a. Positive Contact</p> <p>i. Face</p> <p>ii. Packings</p> <p>iii. Lip</p> <p>iv. Rings</p> <p>v. Diaphragms</p> <p>b. Controlled Clearance</p> <p>i. Labyrinth</p> <p>ii. Bushing</p> <p>2. Control of Fluid Properties</p> <p>a. Freeze</p> <p>b. Magnetic</p> <p>3. Control of Forces</p> | <p>C. <u>Reciprocating Motion</u></p> <p>1. <u>Selection and Control of Geometry</u></p> <p>a. Positive Contact</p> <p>i. Packings</p> <p>ii. Lip</p> <p>iii. Rings</p> <p>iv. Diaphragm</p> <p>b. Controlled Clearance</p> <p>i. Labyrinth</p> <p>ii. Bushing</p> <p>2. Control of Fluid Properties</p> <p>a. Freeze</p> <p>b. Magnetic</p> <p>3. Control of Forces</p> |
|---|--|--|

II. STATIC SEALS

- | | | | |
|--|--|--|------------------------------------|
| <p>A. <u>Selection and Control of Geometry</u></p> <p>1. Positive Contact</p> <p>i. Elastic Deformation</p> <p>Gaskets</p> <p>Rings</p> <p>Diaphragms</p> <p>ii. Plastic Deformation</p> <p>Gaskets</p> <p>Rings</p> | <p>A. <u>Selection and Control of Geometry (Continued)</u></p> <p>iii. Hermetic Sealing</p> <p>Welding</p> <p>Brazing</p> <p>Soldering</p> <p>Cementing</p> <p>Mold in place seals</p> <p>2. Controlled Clearance</p> <p>i. Labyrinth</p> <p>ii. Bushing</p> | <p>B. <u>Control of Fluid Properties</u></p> <p>1. Freeze</p> <p>2. Magnetic</p> | <p>C. <u>Control of Forces</u></p> |
|--|--|--|------------------------------------|

RECOMMENDED GENERAL REFERENCES

The Seals Book - Jan. 19, 1961, Produced by Machine Design, The Penton Publishing Co. - Penton Building, Cleveland 13, Ohio.

SAE Aerospace Standards, Recommended Practices, Information Reports - Cooperative Engineering Program - Society of Automotive Engineers, 485 Lexington Avenue, New York 17, N. Y.

Surface Texture - ASA-B46.1-1962, Surface roughness, waviness and lay.

Surface Roughness, Waviness and Lay-Military Standard - MIL-STD-10A.

Surface Roughness - SAE Aeronautical Standard AS291B - Surface Roughness

Surface Finish Control - SAE Recommended Practice SAEJ449.

The Accuracy of Surface Roughness Assessment by P. F. Jones - Microtechnic Vol. XVI No. 3, pp. 105-112.

Scientific Foundations of Vacuum Techniques by Saul Dushman, Second Edition 1962, John Wiley Publishing Co.

LIST OF TABLES

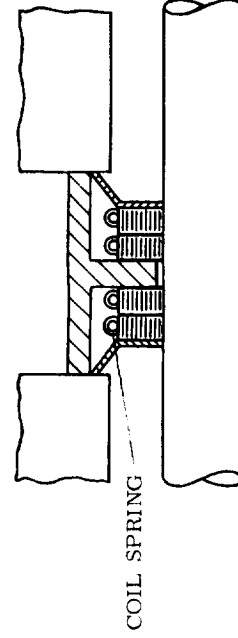
<u>SEAL TYPE</u>	<u>TABLE NO.</u>
Bushings	1
Caulking (Static)	2
Face or Axial	3
Gasket (Static Seal)	4
" (" ")	5
" (" ")	6
Hermetic	7
Lip or Radial (Dynamic)	8
Packing-Stuffing (Dynamic)	9
Packing-Stuffing Box (Static)	10
" - " " (")	11
Misc. Rings (Dynamic)	12
O-Ring (General)	13
O-Ring (Dynamic Seal)	14
" (" ")	15
" (" ")	16
O-Ring (Static)	17
" (")	18
" (")	19
"V"-Ring (Dynamic)	20
Special Sealing Concepts (Static)	21

SEAL ANALYSIS

SEAL TYPE Bushings

TABLE 1

REFERENCE	SEAL ANALYSIS	SEAL TYPE	Bushings
NO.	B. L. Johnson June 1958 AD201739	H. O. Pederson etal., Feb. 1959 AD223213	
TYPE OF INFORMATION	X	In Fixture	
TESTS			
RECOMMENDATION			
TEMPERATURE °F			
MAX.			
RANGE			
MOTION-TYPE			
VELOCITY FPM			
MATERIAL			
SEAL			
MATE			
PRESSURE PSIA			
MAX.			
RANGE			
LOADING			
SPRING			
COMPRESSION			
SURFACE FIN. (μ in CLA)			
LEAK RATE (Atm. cc/sec)			
FLUID			
TEST DURATION			
LIFE			
REMARKS			
DESIGN			



SEAL ANALYSIS

SEAL TYPE Caulking (Static)

TABLE 2

<u>REFERENCE</u>	<u>SEAL TYPE</u>	<u>Caulking (Static)</u>
<u>NO.</u>		
<u>TYPE OF INFORMATION</u>		
<u>TESTS</u>		
<u>RECOMMENDATION</u>		
<u>TEMPERATURE °F</u>		
<u>MAX.</u>		
<u>RANGE</u>		
<u>MOTION-TYPE</u>		
<u>VELOCITY FPM</u>		
<u>MATERIAL</u>		
<u>SEAL</u>		
<u>MATE</u>		
<u>PRESSURE PSIA</u>		
<u>MAX.</u>		
<u>RANGE</u>		
<u>LOADING</u>		
<u>SPRING</u>		
<u>COMPRESSION</u>		
<u>SURFACE FIN. (in. CLA)</u>		
<u>LEAK RATE (Atms. cc/sec)</u>		
<u>FLUID</u>		
<u>TEST DURATION</u>		
<u>LIFE</u>		
<u>REMARKS</u>		
<u>DESIGN</u>		

Scharfenstein, C.F. May 1958 AD218038	Pigman, S.S. April 1958 AD200230	R. W. Bryant et al July 1958 AD200898	Bashfield, W.H. Dec. 1955 AD94590
X	X	X	X
	500	cycling	140
Min. Mining Chrome-Lock Tape Type N-MIL-G 20241, Symbol 2291 PRC 1201T Caulk Mat. Al to Al; Fe to Al Joint	Silicone Base Sealer Insulated Cable	Threaded Joint RDI286 Cement RDI284 Luting MK8 4 1/2 Ft Drop to concrete	Glass Solder 97 1/2% Pb 2 1/2% Ag 0.7
10% Aqueous Na-Ce 30 days plus 200 hrs. Accel. Weathering Most Satisfactory Method	Air 96 hrs. Little Change in Insul. Resis.		Air Satisfactory at 500 V. RMS
		Avoid Dissimilar metals	
		Use Shoulder on Threaded Part	
		See Also AD154972	

DESIGN

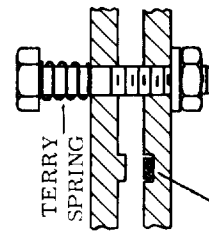
Figure 1 illustrates the design of the carbide jet blades, showing a cross-sectional view and a top-down view. The cross-sectional view (right) shows the rotating plate assembly, including the aluminum oxide layer, the 25% glass filled teflon sealant, and the force applied to the rotating plate. The top-down view (left) shows the rotating plate, the graphite-base rings, and the stationary component, with a section line A-A indicating the location of the cross-section.

SEAL ANALYSIS

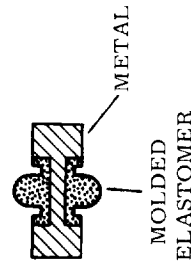
SEAL TYPE Gaskets (Static Seal)

TABLE 4

REFERENCE		R. H. Dawton Oct. 1957 D-014		J. Jordan, et al. April 1960 J027		Anonymous Sept. 1954 AD41652			
NO.									
TYPE OF INFORMATION									
TESTS	N	N				X	X		
RECOMMENDATION									
TEMPERATURE °F	300C	200C					After Water Tests - 400		
MAX.									
RANGE	70 to 572	70 to 392							
MOTION-TYPE									
VELOCITY FPM									
MATERIAL							Silastic #675		
SEAL	Silastic					Buna N	Viton A		
MATE	Metal					Neoprene	Silicone		
PRESSURE PSIA							Rubber Nat.		
MAX.							Butyl		
RANGE	0 to 14.7					-80 to 275	-80 to 275		
LOADING							-65 to 350	-180 to 500	
SPRING							-80 to 300	-65 to 450	
COMPRESSION							X	X	
SURFACE FIN. (μ in. CLA)							X	X	
LEAK RATE (Atm. cc/sec)							X	X	
FLUID	Air	100 Hrs.	Oil & Liquid Fuel	Water, Steam, Ozone	Hyd. Oils Phos. -Ester Based	Water	Hot Air Phos. Esters Alcohols	Hydrocarbons Fuels, Lub. Oil, Disebacate Esters & Siloxane	Water Spray & Submersion
TEST DURATION	70 Hrs.	100 Hrs.	At 450F 60 to 70 Hrs.	At 450F 80 Hrs.			At 450F 100 Hrs.	At 450F 95 Hrs.	
LIFE									
REMARKS									



1/16" GASKET



SEAL ANALYSIS

SEAL TYPE Gaskets (Static Seal)

T A B L E

5

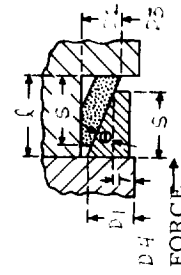
REFERENCE	SEAL ANALYSIS	SEAL TYPE	Gaskets (Static Seal)	T A B L E
NO.	M. B. Donald 1955 D057		Met. Vickers Sept. 1949 MV9804	J. W. Hull Sept. 1960 H079
TYPE OF INFORMATION				
TESTS	N	X	X	X
RECOMMENDATION				
TEMPERATURE °F	70F		194	20 to 550C (68 to 1022)
MAX. RANGE				-65 to 700
MOTION-TYPE				
VELOCITY FPM				
MATERIAL SEAL	Rubber Bonded Asbestos Fiber (Kingerit) Metal	Soft Iron	Lagnite	Al
MATE		Cu, Fe	Metal	Steel
PRESSURE PSIA				
MAX. RANGE	1615		29.7	4000
LOADING			14.7	Surge 6000
SPRING COMPRESSION			24.7	
SURFACE FIN. (μ in. CLA)				To 4100 lb/in
LEAK RATE (Atm. cc/sec)	0	10 ⁻⁹	0	Fine Emery on Ring 0
FLUID	Water	Air	Oil	Hydraulic Fluids
TEST DURATION			10 days	10 Cycles
LIFE			7 days	
REMARKS			20 Hrs.	
DESIGN				Design Formu- lae and Tables are given

$$\theta = 15^{\circ} \text{ to } 20^{\circ}$$

$$D_4 = D_1 - 2 (S \tan \theta + T)$$

$$D_3 = D_2 - 2 (\angle \tan \theta + T)$$

SEE (H079)



SEAL ANALYSIS

SEAL TYPE

Gaskets (Static Seal)

TABLE 6

REFERENCE	A. E. Barrett Sept. 1956 AD145361	M. Sabanas April 1960 AD238020		L. N. Navarre, etal., Feb. 1951 AD204937
NO.				
TYPE OF INFORMATION				
TESTS	X	N	X	X
RECOMMENDATION				
TEMPERATURE °F				
MAX.				
RANGE				
MOTION-TYPE				
VELOCITY FPM				
MATERIAL				
SEAL				
MATE				
PRESSURE PSIA				
MAX.				
RANGE				
LOADING				
SPRING				
COMPRESSION				
SURFACE FIN. (μ in, CLA)				
LEAK RATE (Atm. cc/sec)				
FLUID				
TEST DURATION				
LIFE				
REMARKS				
DESIGN				

REFERENCES:

- Society of Automotive Engineers: ARP 748, ARP 453;
 Aerospace Standards - Cooperative Engineering Program (See General References)
 American Standards Association: ASA-B16. 21 -1962 Nonmetallic Gaskets for Pipe Flanges
 ASA-B16. 20-1956 Ring-Joint Gaskets and Grooves For Steel Pipe Flanges
 Chemical Engineering Oct. 1, 1962, pp. 83-88, "Select and Apply Gaskets Effectively" by J. J. Wahlen

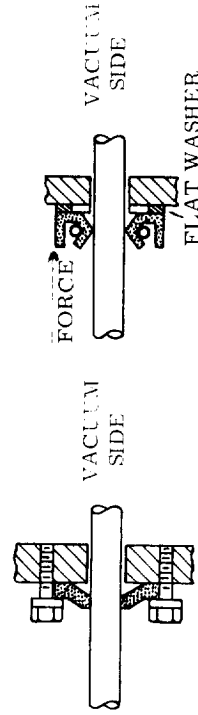
SEAL ANALYSIS

SEAL TYPE Hermetic

TABLE 7

<u>REFERENCE</u>		Bashfield, W. H. Dec. 1955 AD94590
<u>NO.</u>		
<u>TYPE OF INFORMATION</u>		
<u>TESTS</u>		X
<u>RECOMMENDATION</u>		
<u>TEMPERATURE °F</u>		
<u>MAX.</u>		140
<u>RANGE</u>		
<u>MOTION - TYPE</u>		
<u>VELOCITY FPM</u>		
<u>MATERIAL</u>		glass
<u>SEAL</u>		
<u>MATE</u>		Solder 97 1/2% Pb 2 1/2 % Ag
<u>PRESSURE PSIA</u>		
<u>MAX.</u>		0.7
<u>RANGE</u>		
<u>LOADING</u>		
<u>SPRING</u>		
<u>COMPRESSION</u>		
<u>SURFACE FIN. (in. CLA)</u>		
<u>LEAK RATE (Atms. cc/sec)</u>		
<u>FLUID</u>		Air
<u>TEST DURATION</u>		
<u>LIFE</u>		Satisfactory at 500V rms
<u>REMARKS</u>		
<u>DESIGN</u>		

REFERENCE	R. H. V. M. Dawton			
NO.	Oct. 1957 D-014			
TYPE OF INFORMATION				
TESTS	X	X	X	X
RECOMMENDATION				
TEMPERATURE °F				
MAX. RANGE	120C 248	120C 248	70	70
MOTION TYPE				
VELOCITY FPM	Rotation	Reciprocating (2")		
MATERIAL SEAL	6 1 Rev/sec, 3/8 diam.			
MATE	Neoprene			
PRESSURE PSIA	Steel	Buffed Steel	S. S.	
MAX. RANGE	Glass			
LOADING	Brass			
SPRING COMPRESSION				
SURFACE FIN. (in. CLA)				
LEAK RATE (Atms. cc/sec)	5 x 10 ⁻⁶	1.5 x 10 ⁻⁵	4.5 x 10 ⁻⁵	
FLUID	Air			
TEST DURATION	200 hrs.	per stroke	per stroke	
LIFE	2 days			
REMARKS	Lubrication: Apiezon "B" Oil			



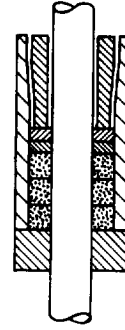
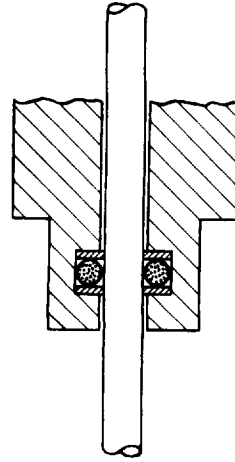
REFERENCES: SAE-J110 "Bench Leakage Test for Automotive Radial Oil Seals For Rotating Shafts", SAE-J111 "Radial Seal Nomenclature", Paper No. 473A - Society of Automotive Engineers - "Engineering Facts About Lip Seals" by J. D. Symons, Jan. 1962 (SI04)

SEAL ANALYSIS

SEAL TYPE Packing-Stuffing (Dynamic)

TABLE 9

REFERENCE NO.	SEAL ANALYSIS	SEAL TYPE	Packing-Stuffing (Dynamic)	
F. R. Straus Jan. 1955 AD74089				R. B. Resek July 1956 AD97258
TYPE OF INFORMATION				
TESTS RECOMMENDATION	X	X	X	X
TEMPERATURE °F MAX. RANGE	-40 Prior Exposure to 300F	80	500	80
MOTION-TYPE	Tests to Determine Effect of 40,000 Cycles at 300F	Test for Effect of 50000 cy.at 80F		Reciprocating-6" Travel at 30 Cycles per Min.
VELOCITY FPM				
MATERIAL SEAL	O-Ring Neo- prene WRT Compound with Spiral Teflon Back-up Rings 25	AN6227	453-26C	Ring Packing (MX4439 Cumpac Seal) - Johns-Manville - 95% Asbestos with Inconel Wire Mesh Core
PRESSURE PSIA MAX.	3000			
RANGE				
LOADING SPRING COMPRESSION				Cycling 200 to 3000
				50 Lb-Ft
SURFACE FIN. (μ in CLA)				
LEAK RATE (Atm. cc/sec)	0	.007	Satisfactory	3.4 cc/1000 cyc. 2.6cc/1000 cyc.
FLUID	Hydraulic Oil ML08200	Hydraulic Oil MIL-0-5606	Hydraulic Oil	
TEST DURATION	20 Hrs.	1 Hr.	50,000 Cycles	5000 Cycles 25,000 Cycles
LIFE			5 Hrs.	3 Hrs.
REMARKS			1.5 Hrs.	14 Hrs.
DESIGN				

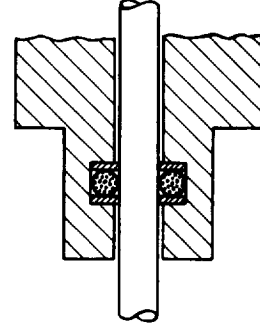
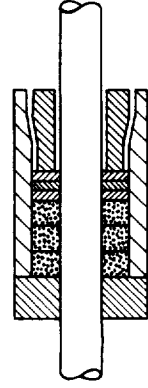


SEAL ANALYSIS

SEAL TYPE Packing-Stuffing Box (Static)

TABLE 10

REFERENCE	SEAL ANALYSIS		SEAL TYPE Packing-Stuffing Box (Static)		F. R. Straus Jan. 1955 AD74089	
NO.	M. W. Varrell May 1957 AD140116	R. B. Resek July 1956 AD97258				
TYPE OF INFORMATION	X		X	X	X	X
TESTS						
RECOMMENDATION						
TEMPERATURE °F		30	30	400	400	500
MAX. RANGE						-65 to +400
MOTION-TYPE		Hydraulic Actuator Rod			Preconditioned with 40,000 Cycles at 300F	
VELOCITY FPM						
MATERIAL		95% Asbestos Packing Ring Inconel Wire Mesh Core (MX 4439 Cumpac Seal) Johns-Manville			Neoprene WRT Compound with Spiral Teflon Back-up Rings	453-26C O-Ring Comp. 453-9A, 1203-70
SEAL	#73902-5 Ring Packing Plug - Sonar Stuffing Tube 1000	25	3000	10	3000	
MATE						
PRESSURE PSIA						
MAX. RANGE						
LOADING		50 Lb-Ft				
SPRING COMPRESSION						
SURFACE FIN. (μ in. CLA)	Satisfactory					
LEAK RATE (Atm. cc/sec)		0	0	0	0	.007
FLUID	Water	OS-45 Hydraulic Oil			ML0-8200 Hydraulic Oil	Hydraulic Oil
TEST DURATION		1 Hr.	1 Hr.	1 Hr.	20 Hrs.	1 Hr.
LIFE						5 Hrs.
REMARKS						
DESIGN						



SEAL ANALYSIS

<u>REFERENCE</u>	F. R. Straus Jan. 1955 AD74089
<u>NO.</u>	
<u>TYPE OF INFORMATION</u>	X
<u>TESTS</u>	
<u>RECOMMENDATION</u>	
<u>TEMPERATURE °F</u>	550
<u>MAX.</u>	
<u>RANGE</u>	
<u>MOTION-TYPE</u>	
<u>VELOCITY FPM</u>	
<u>MATERIAL</u>	453-9A
<u>SEAL</u>	1203-70
<u>MATE</u>	O-Ring Comp.
<u>PRESSURE PSIA</u>	
<u>MAX.</u>	
<u>RANGE</u>	
<u>LOADING</u>	
<u>SPRING</u>	
<u>COMPRESSION</u>	
<u>SURFACE FIN. (μ in. CLA)</u>	
<u>LEAK RATE (Atm. cc/sec)</u>	Satisfactory
<u>FLUID</u>	Hydraulic Oil
<u>TEST DURATION</u>	1.5 Hrs.
<u>LIFE</u>	
<u>REMARKS</u>	
<u>DESIGN</u>	

SEAL ANALYSIS

SEAL TYPE Misc. Rings (Dynamic)

REFERENCE

M. H. Everett
Jan. 1961
E034

NO.

TYPE OF INFORMATION

TESTS

RECOMMENDATION

TEMPERATURE OF
MAX.
RANGE

MOTION-TYPE

VELOCITY FPM

MATERIAL
SEAL

MATE

PRESSURE PSIA
MAX.

RANGE

LOADING
SPRING

COMPRESSION

SURFACE FIN. (μ in CLA)

LEAK RATE (Atm. cc/sec)

FLUID

TEST DURATION

LIFE

REMARKS

DESIGN

X X X X X

-20 to 350F -20 to 250 -65 to 225 -130 to 500 -100 to 350 600
-40 to 450

Reciprocating - Rotating - Oscillating

Rot. 350-600 Not Gen. Recom. Rot. 350-600
for Dyn. Uses

Polyacrylate- acrylic Acid Ester Polymer Butyl Rubber Polysulfide Polymer Silicone Polymers Hexafluoropro- pylene & Vinyl- idene Fluoride Copolymers

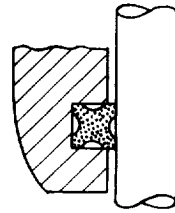
Metal

Peripheral
5%

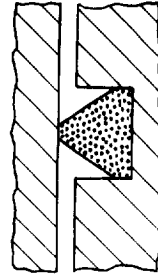
16 to 32

Oil, Ozone Hyd. Fl. of Phos- Ozone, Pet. Base High Aniline Pet. Based Fuel
phate-Ester Fuels & Oils Oils-Hi Temp & Lub. Ester
Gases, Ozone Aromatic Solv. Air-Ozone Type Lub-Hy-
Veg. Oils drocarbons
(Many)

Great Many
Fluids &
Chemicals



X-RING



DELTA-RING

SEAL ANALYSIS

SEAL TYPE O-Ring (General)

TABLE 13

REFERENCE	R. D. Ford Sept. 1957 AD145846	C. E. Hamlin Mar. 1954 AD29114	A. MacCullen May 1960 AD241589
NO.			
TYPE OF INFORMATION			
TESTS	X	X	X
RECOMMENDATION			
TEMPERATURE °F			
MAX.	300	400	275
RANGE		550-Short Time	
MOTION-TYPE			
VELOCITY FPM		Reciprocating 2 cps	Hydraulic Valve & Pump
MATERIAL			
SEAL	Silicone W96	Neoprene W Al-Bronze Back-up	Buna N
MATE			
PRESSURE PSIA			
MAX.		3000	3000
RANGE			
LOADING			
SPRING			
COMPRESSION			
SURFACE FIN. (μ in. CLA)			
LEAK RATE (Atm. cc/sec)	Satisfactory Seal	Satisfactory	Not Abnormal
FLUID	Air and ASTM Oil #2	Orthosilicate Ester Hy- draulic Fluid 100,000 Cycles	Ordnite #8515 Hydraulic Fluid 260 Hrs. Performance Satisfactory
TEST DURATION			
LIFE			
REMARKS			

DESIGN

GENERAL REFERENCES:

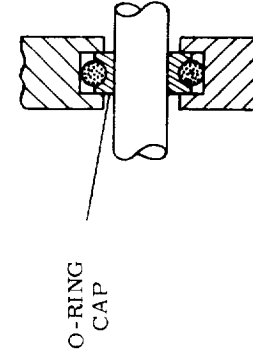
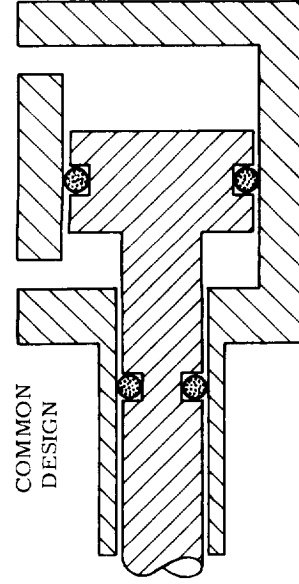
"Design Data for O-Rings and Similar Elastic Seals," by R. S. Roper, F. W. Titon, W. R. Walker, et al. in ASTIA Reports AD230658, AD230639, AD265443.

Oil and Gas Equipment - Dec. 1959
 "O-Rings: Their Uses In Solving Important Sealing Problems" by J. R. Jordan
 Oil and Gas Equipment - Jan. 1960
 "Choosing The Right O-Ring Can Solve Your Sealing Problem" by J. R. Jordan

Society Automotive Engineers
 Recommended Practice - SAE J120 -
 "Rubber O-Rings for Automotive
 Seal and Packing Applications"

REFERENCE	M. H. Everett, et al. Jan. 19, 1961 E034	R. L. Hayman March 1945 H024	R. L. Hayman Jan. 1945 H023	L. E. VanHise, etal., Mar. 1955 AD68495	C. E. Hamlin Mar. 1954 AD29114	J. O. Bruno Dec. 1957 AD118213
NO.						
TYPE OF INFORMATION						
TESTS						
RECOMMENDATION						
TEMPERATURE OF MAX. RANGE						
MOTION-TYPE						
VELOCITY FPM						
MATERIAL						
SEAL						
MATE						
PRESSURE PSIA						
MAX. RANGE						
LOADING						
SPRING COMPRESSION						
SURFACE FIN. (μ in CLA)						
LEAK RATE (Airm. cc/sec)						
FLUID						
TEST DURATION						
LIFE						
REMARKS						

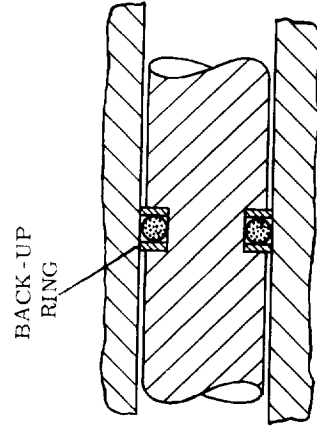
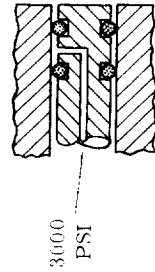
DESIGN



SEAL ANALYSIS

SEAL TYPE "O"-Ring (Dynamic Seal)

REFERENCE	SEAL TYPE	TABLE			15
NO.	F. R. Straus Jan. 1955 AD74089				
TYPE OF INFORMATION					
TESTS					
RECOMMENDATION					
TEMPERATURE °F					
MAX.					
RANGE					
MOTION-TYPE					
VELOCITY FPM					
MATERIAL SEAL					
MATE					
PRESSURE PSIA					
MAX.					
RANGE					
LOADING					
SPRING COMPRESSION					
SURFACE FIN. (μ in CLA)					
LEAK RATE (Atm. cc/sec)					
FLUID					
TEST DURATION					
LIFE					
REMARKS					
DESIGN					



SEAL TYPE O-Ring (Static)

TABLE 17

SEAL ANALYSIS

E. J. Parker
Oct. 1957
P-010

REFERENCE

NO.

TYPE OF INFORMATION

TESTS
RECOMMENDATION

TEMPERATURE °F
MAX.
RANGE

MOTION-TYPE

VELOCITY FPM

MATERIAL
SEAL

MATE

PRESSURE PSIA
MAX.

RANGE

LOADING
SPRING
COMPRESSION

SURFACE FIN. (μ in. CLA)

LEAK RATE (Atm. cc/sec)

FLUID

TEST DURATION

LIFE

REMARKS

DESIGN

X

X

X

X

X

X

X

X

-65 to 300

-65 to 160

-65 to 275

-65 to 170

-65 to 160

-65 to 160

-130 to 400

-20 to 325

-300 to 500

500

Natural
Rubber

Neoprene

Buna N

Thiokol

Butyl

Buna S

Silicone

Acrylate

Teflon

Satisfactory

Water, Steam
Alcohols, Sili-
conesCastor Oil

Refrigerants,
CO₂

Pet. Lub. &
Hyd. Oils
Pet. Fuels

Alcohols, High
Aromatic
Fuels

Phosphate
Ester

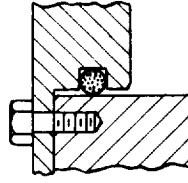
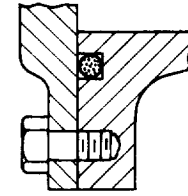
Water
Alcohols
Ketones

Air, Inert Gases-
High Aniline
Point Oils

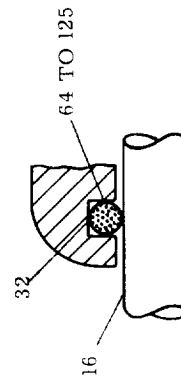
Pet. Oils &
Hydraulic
Fluids

Various
Chemicals

TYPICAL
DESIGNS



REFERENCE	A. MacCullen May 1960 AD241589	S. Iwanami, et al., Nov. 1959 1012	
NO.			
TYPE OF INFORMATION			
TESTS	X	X	
RECOMMENDATION			
TEMPERATURE °F			
MAX.			
RANGE	275	122	
MOTION-TYPE			
VELOCITY FPM	Hydraulic Valve & Pump	Reciprocating 4" Stroke 0.6 ft/sec	1.1 ft/sec 1.7 ft/sec
MATERIAL			
SEAL	Buna N	Acryle-Nitrile Rubber & Chloro- prene JIS	
MATE		Hardness #63	
PRESSURE PSIA			
MAX.	3000	1437	72 157
RANGE			
LOADING			
SPRING			
COMPRESSION			
SURFACE FIN. (μ in CLA)			
LEAK RATE (Atm. cc/sec)	Not Abnormal	2.7 x 10 ⁻⁴	11 x 10 ⁻⁴ 20 x 10 ⁻⁴ 2.7 x 10 ⁻⁴ 8 x 10 ⁻⁴
FLUID	Oronite #8515 Hydraulic Fluid	Aircraft Hydraulic Oil	
TEST DURATION	260 Hrs.		
LIFE	Performance Satisfactory		
REMARKS	Radiation Dose 10 ⁹ ergs/g (C)		
DESIGN			

SURFACE
FINISHES

SEAL ANALYSIS

SEAL TYPE O-Ring (Static)

TABLE 18

REFERENCE	E. J. Parker Oct. 1957 P-010				M. W. Varrell May 1957 AD140116	F. O. Riek Feb. 1953 AD11484	S. Iwanami, et al Nov. 1959 I-012
NO.							
TYPE OF INFORMATION							
TESTS							
RECOMMENDATION							
TEMPERATURE, °F							
MAX.							
RANGE							
MOTION-TYPE							
VELOCITY FPM							
MATERIAL							
SEAL							
MATE							
PRESSURE PSIA							
MAX.							
RANGE							
LOADING							
SPRING							
COMPRESSION							
SURFACE FIN. (μ in. CLA)							
LEAK RATE (Atm. cc/sec)							
FLUID							
TEST DURATION							
LIFE							
REMARKS							
DESIGN							

$$W/L_0 = 4.8 \times 10^{-7} \times d^{1.2} \times \epsilon^{1.3} \times H^{4.5} \quad (\text{Where } \epsilon < 6.15)$$

(Source I-012)

W = Compressive Load (kg)

d = Material Diam. (cm)

 $\epsilon = \delta / d$ δ = Deformation Magnitude (cm)

H = JIS Hardness

 L_0 = Outer Ring Circumference (cm)

SEAL ANALYSIS

SEAL TYPE O-Ring (Static)

TABLE 19

F. R. Straus
Jan. 1955
AD74089

NO.

TYPE OF INFORMATION

TESTS
RECOMMENDATION

TEMPERATURE °F

MAX.
RANGE

MOTION - TYPE

VELOCITY FPM

MATERIAL

SEAL

MATE

PRESSURE PSIA

MAX.

RANGE

LOADING

SPRING

COMPRESSION

SURFACE FIN. (μ in. CLA)

LEAK RATE (Atm. cc/sec)

FLUID

TEST DURATION

LIFE

REMARKS

DESIGN

N

-40

Preconditioned with 40,000
Cycles at 300FNeoprene WRT-
Spiral Teflon
Back-up Rings
on Both Sides

25

3000

453-26C
O-Ring
Compound

453-9A

453-9A
1203-70

AF934

AF934

Silicone
W96Silicone
W96

0

.007

Satisfactory

0

0

ML08200 Hydraulic Oil

Isooctane

70% Isooctane ASTM Oil No. 2
30% PhMe ASTM Oil No. 3

20 Hrs.

1 Hr.

5 Hrs.

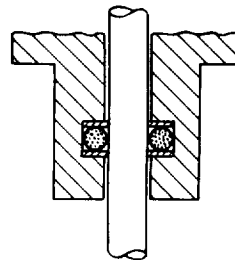
1.5 Hrs.

37 days

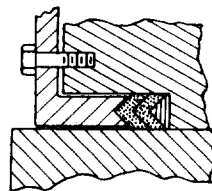
37 days

Satisfactory

Satisfactory

TESTED FOR
STATIC PERFORMANCE

SEAL ANALYSIS		SEAL TYPE		"V"-Ring (Dynamic)	
REFERENCE		J. N. Smith			
NO.		Jan. 1961			
		S-070			
TYPE OF INFORMATION					
TESTS					
RECOMMENDATION					
TEMPERATURE °F					
MAX.					
RANGE					
MOTION-TYPE					
VELOCITY FPM					
MATERIAL					
SEAL					
MATE					
PRESSURE PSIA					
MAX.					
RANGE					
LOADING					
SPRING					
COMPRESSION					
SURFACE FIN. (μ in CLA)					
LEAK RATE (Atm. cc/sec)					
FLUID					
TEST DURATION					
LIFE					
REMARKS					
DESIGN					



SEAL ANALYSIS

SEAL TYPE Special Sealing Concepts (Static)

TABLE 21

REFERENCE	Islinger, J.S. June 1956 AD106754	House, P.A. Feb. 1962 AD273284	E. T. Leidigm et al June 1957 AD140572
NO.			
TYPE OF INFORMATION			
TESTS	X	X	X
RECOMMENDATION			
TEMPERATURE °F			
MAX.			
RANGE	-85 to 200		Cycling -65 to 160F
MOTION-TYPE			
VELOCITY FPM			
MATERIAL			
SEAL	Silicone Rubber	Thickened Poly- Propylene Oxide - Toluene Diisocyanate and Triethylene Tetramine	Polyurathane Foam
MATE			
PRESSURE PSIA			
MAX.	27		
RANGE			
LOADING			
SPRING			
COMPRESSION	Inflated		
SURFACE FIN. (in. CLA)			
LEAK RATE (Atms. cc/sec)			
FLUID	Seal out Moisture Air	Seals punctures caused by 22 caliber bullets	No exudation
TEST DURATION	1000 Open & Close Cycles		4 Weeks
LIFE	At 75F & 25		
REMARKS	At -65F Aircraft Canopy Seal	Punctured Wall Sealer Hollow wall containing two fluids separated by membrane. Puncture causes fluids to mix and solidify.	Bomb Sealer
DESIGN			
			General Reference - Encapsulants: AD97767 (ASTIA) Investigating Encapsulants For Ground Electronic Equipment. June 1956 - Battelle Memorial Institute

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SCHENECTADY, NEW YORK

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